



Summary Report: Technology for Fundamental Space Biology Workshop

Sponsored by NASA Ames Research Center
October 22-24, 2002
Palo Alto, California USA

Coordinated by:

John Hines

Manager, Biomolecular Physics and Chemistry Program;
Sr. Technology Program Manager,
Fundamental Space Biology Research Program;
Manager, Bioastronautics Advanced Technology Development Projects
NASA Ames Research Center

Gregory Kovacs, MD, PhD

Associate Professor of Electrical Engineering and (by courtesy) Medicine
Stanford University

Antonio J. Ricco, PhD

Sr. Director, Microtechnologies & Materials
ACLARA BioSciences, Inc.

Report Date: 12/22/02

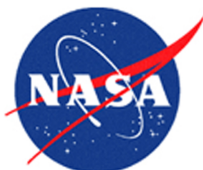


TABLE OF CONTENTS

I. Executive Summary	1
II. Introduction/Goals	
A. Workshop Objectives	3
B. Workshop Approach	4
1. Charge to Workshop	
2. OBPR Fundamental Research Objectives	
III. Workshop	
A. FSB Program Objectives	5
1. Science	
2. Technology	
3. Missions	
B. New Biology & Technology (Tutorial)	7
C. Technology Breakout Session	7
1. Sample Management	
2. Bioanalytical Technologies	
3. Imaging/Photonics	
D. Strategic Vision and Technology Insertion Breakout Session	11
1. Define Strategies for a Technology Roadmap	
2. Define Strategies for Technology Development & Insertion	
3. Define Science/Technology Collaboration Options	
E. Science Scenario Breakout Session	12
1. Yeast/Bacteria/Mammalian Cells	
2. Nematodes/Fruit Flies	
3. Plants	
4. Rodents/Humans	
F. Recommendations	16
1. Technology	
2. Science	
3. Implementation	
G. Conclusion	18
III. Attachments	
A. Agenda	
B. Biographical Sketches of Coordinators	
C. Attendee List	
D. Example Quad Charts	
E. Session I & II Worksheets	
F. Technology Roadmap Diagram	
G. List of Science and Technology Quad Charts	
H. OBPR-wide Fundamental Research Objectives	

I. EXECUTIVE SUMMARY

A. Introduction

Advanced, miniaturized technologies are critical for helping solve current space access constraints and expanding opportunities to gain fundamental biological knowledge and apply it to human space exploration challenges. These technologies can help provide earlier access to space on the ISS and other space platforms, require little or no crew time, and support near-term high-priority cell and molecular biology experiments in Shuttle middeck locker and smaller sized payloads.

Based on this strategy, the Fundamental Space Biology (FSB) Office at the NASA Ames Research Center (ARC) sponsored a workshop to identify biological technologies of the type that can be assembled as autonomous, miniaturized, and integrated systems to support next-generation FSB space flight research. Attendance at the workshop was by invitation only and included a broad mix of science, technology, and strategic planning experts. Conducted on October 22-24, 2002 in Palo Alto, CA, the Technology for Fundamental Space Biology (T4FSB) workshop focused on the high-priority technology areas that support sample processing, bioanalysis, and imaging of selected genomically-defined model organisms ranging from cells to small plants and animals.

A pre-workshop tutorial session was held to update participants on the state of the art in biology and associated technologies. The workshop proper began with presentations covering the FSB program objectives related to science, technology, and space flight missions. Working sessions then identified applicable and appropriate technologies, developed science scenarios for specific model organisms that would take advantage of these technologies to maximize science return and flight opportunities, and suggest investment strategies for development and insertion of technologies.

B. Results/Recommendations

Key output from the working group sessions is as follows:

1. Technology

- Aggressively pursue freezing and preservation technologies
- Explore digital imaging, spectroscopy, and fluorescence for flight applications
- Pursue biofluidics technologies for autonomous, in situ science payload scenarios

2. Implementation

- Rapidly demonstrate early value-added technologies and integrated systems to verify the overall value of the approach
- Investigate passive (no upmass resource requirements) payload carriers and instruments for ISS Assembly-era flights
- Closely link strategic technology development activity to manned space flight and human exploration thrusts

3. Programmatics

- Emphasis on low-barrier access to space
- Institutionalization of the interdisciplinary, interagency brainstorming format demonstrated in the workshop
- Continue focus groups and science/technology working groups to define/compile requirements, assess technologies, assign priorities, and form collaborative development teams

C. Conclusion

The T4FSB workshop provided a unique opportunity for scientists and engineers to exchange information and ideas about technology needs and capabilities. Enthusiasm was expressed by many attendees for the significant knowledge gained at the event.

The workshop showed that NASA space biology research can benefit greatly from R&D in the commercial sector and that similar requirements to NASA's exist, especially in the health and defense sectors. These requirements, including miniaturization, automation and modularity, will allow leveraging and co-development projects to be conducted. Representatives of the biotechnology community indicated their strong interest in participating in post-workshop FSB activities.

Next steps will include further definition of science and operational requirements for translation into detailed technology needs. More detailed definition of experiment scenarios will be done using model organisms within a middeck locker payload element on each of the targeted platforms—ISS, free flyers, and nanosatellites. This work will be conducted in focus groups organized around specific technologies and science applications. Collaborative teams will further define technologies and methods of leveraging and co-development to minimize costs for each participating organization. The program will develop a Fundamental Space Biology Technology Roadmap to guide targeted technology development for insertion in the flight hardware development process.

II. INTRODUCTION/GOALS

A. Workshop Objectives

The Technology for Fundamental Space Biology (T4FSB) workshop was conducted on October 22-24, 2002 in Palo Alto, CA and sponsored by the Fundamental Space Biology (FSB) Office at the NASA Ames Research Center (ARC).

Advanced, miniaturized technologies are critical for helping solve current space access constraints and expanding opportunities to gain fundamental biological knowledge and apply it to human space exploration challenges. These technologies can help provide earlier access to space on the ISS and other space platforms, require little or no crew time, and support near-term high-priority cell and molecular biology experiments in Shuttle middeck locker and smaller sized payloads. Ready-to-fly autonomous science payloads are essential for missions of opportunity that arise on short notice. Addition of such technologies to near-term emerging ISS flight hardware can also provide expanded research capabilities across the OBPR Enterprise and probably other NASA Enterprises. In this way constrained NASA technology development resources can be leveraged for both near-term and longer-term support of space research.

The technology drivers for the workshop were to identify biological technologies of the type that can be assembled as autonomous, miniaturized and integrated systems to support next-generation FSB space flight research. The workshop focused on technologies that primarily support sample processing, bioanalysis, and imaging of selected genomically defined model organisms ranging from cells to small plants and animals. The science drivers were derived from the science goals and objectives of the FSB Division within the NASA Office of Biological & Physical Research (OBPR) and the FSB Program Office at ARC.

Attendance at the workshop was by invitation only and included: a broad mix of science, technology, and strategic planning experts including distinguished scientists and engineers from NASA, other government labs and organizations, academia, industry and private laboratories (Attachment C). Workshop participants were instructed to consider technologies that could be flown on one or more of the following space platforms: the ISS/STS, autonomous free-flyers and nanosatellites.

The workshop was led by three interdisciplinary biotechnology and biosciences experts: John Hines, NASA Senior Technology Program Manager for the Fundamental Space Biology Research Program; Gregory Kovacs, MD, PhD, Associate Professor of Electrical Engineering at Stanford University; Tony J. Ricco, PhD, Senior Director of Microtechnologies & Materials at ACLARA Biosciences, Inc. (See Attachment B for more detailed biographical sketches of the coordinators.)

B. Workshop Approach

Prior to the workshop invitees were asked to submit brief descriptions of technologies (relevant to FSB research objectives) and science scenarios (for model organism studies) in the form of “quad charts” (see examples of both in Attachment D and a complete list in Attachment G). The quad charts were launched on the T4FSB workshop Web site (t4fsb.arc.nasa.gov) prior to the event for review and will be considered part of this report which will also reside on the site.

1. Charge to Workshop

- Review applicable and appropriate technologies for supporting and monitoring life processes in model biological organisms, cells and molecular systems
- Provide input to a technology development roadmap for FSB based on representative science and mission objectives, technology development status, and/or availability
- Identify potential sources for recommended technologies and teaming and leveraging possibilities—commercial, academic, and national laboratories are prime candidates
- Suggest investment strategies for development and insertion of technologies in a timely and cost-effective manner

2. OBPR Fundamental Research Objectives

Technologies developed for FSB will contain many generic elements with application to support of several OBPR-wide research objectives. Leveraging of resources across OBPR and across NASA is an essential element of the development strategy for new enabling technologies. OBPR top-level research categories are detailed in Attachment H to this report.

III. WORKSHOP

The following represents a summary of topics presented and discussed during the workshop as per the agenda (Attachment A), without attribution. The presenters and Breakout Session facilitators are listed in the agenda for each topic area.

A. FSB Program Objectives

1. Science

FSB science priorities focus on two major objectives: 1) understanding and ameliorating problems that may limit astronauts' ability to survive and/or function during prolonged space flight and 2) understanding fundamental biological processes in which gravity plays a direct role. Specific science questions include:

- Cell Biology
 - Gain fundamental knowledge of influences of absence of gravity
 - Understand regulation of cell proliferation, gene action, and differentiation
 - Study cellular functions that relate to future space exploration
- Plant Biology
 - Gain basic understanding of effects of gravity on plants
 - Look at utilization for long term space travel
- Developmental Biology
 - Look at reversibility of microgravity responses
 - Study compatibility with life over several generations
 - Understand changes from one generation to the next

Model organisms will be an important tool for answering these questions. Model organisms emerged out of the genome sequencing projects of the late 1990s. These comparatively simple organisms historically used for research—bacteria (*E. coli*), yeast (*S. Cerevisiae*), the nematode worm (*C. elegans*), the fruit fly (*Drosophila*), and others—are now understood at the genetic level. They are providing new insights into the essential biological properties (genes, proteins, metabolic pathways) that they share with each other and more importantly, with humans. The genome sequence for the mouse—a valuable mammalian model—also was recently completed and extends the exciting list of model organisms accessible for modern biological research.

More information on the model organisms believed to be appropriate for research in space biology can be found at t4fsb.arc.nasa.gov.

2. Technology

FSB needs technologies supporting the full scope of biological flight experiments from housing organisms to collecting data to preserving samples. For the purposes of the workshop, three technology drivers were examined:

- **Sample Handling:** Technologies for obtaining, preparing, and processing biosamples
- **Bioanalytical Technologies:** Detection of chemicals and gases and quantitative cytometry, spectrometry, and spectroscopy tools
- **Imaging/Photonics:** Miniature cameras, microscopes, multi-spectral imaging, laser scanning, scanning probe techniques, nmr, IR, far IR, associated technologies such as dyes, tags, and molecular markers

3. Missions

The workshop considered science and technology priorities in the context of three space flight platforms: the International Space Station/Shuttle Middeck, the Cosmos free flyer, and nanosatellites. For all platforms, standard limitations and constraints apply: mass, volume, power, operational duration, and crew interaction/support. For discussion purposes, the unit for payload volume measurement was the Middeck Locker (MDL) configuration (10 x 17 x 20 inches).

- **ISS/Shuttle Middeck**
 - Human presence, semi-autonomous operations
 - Full MDL payload volume
 - Sample return, low earth orbit, 30–180 day missions
 - Middeck has severe up/down power limitations
- **Free Flyer**
 - Fully autonomous operations
 - 1–4 MDL volume with total payload of 700 kg
 - Sample return
- **Nanosatellite**
 - Fully autonomous operations
 - 1/3–1/2 MDL volume
 - Severe mass and volume restrictions will require miniaturized systems
 - No sample return on initial missions

B. New Biology & Technology (Tutorial)

A half-day tutorial (see Attachment A, October 22nd) was held prior to the workshop to familiarize participants with current biology and the state of the art in relevant technology areas. These presentations are listed below and can be found at t4fsb.arc.nasa.gov along with all workshop presentations (authorship included on each presentation):

- Basic Processes of Life; The Big Picture
- Chemical and Biological Sensors; Technologies & Issues
- Separation and Biofluidics Technologies
- Advanced Photonics Technologies
- Microfluidics Technologies; Design Issues
- Miniaturization Issues; Pros & Cons

C. Technology Breakout Sessions

The first day's breakout sessions focused on defining enabling technologies and components for FSB research. Session participants broke into three groups to identify applicable state-of-the-art and emerging technologies in one of the following areas: 1) Sample Management, 2) Bioanalytical Technologies, and 3) Imaging/Photonics. For each identified technology, participants were to indicate:

- Capabilities provided
- Development status
- Projection of when they might be ready for FSB use

When assessing technologies, participants were asked to consider several technology and system issues of importance to FSB implementation. The most pressing included:

- Operation in microgravity and radiation environments
- Calibration (initial/remote): accuracy and stability
- Automation and reprogramability
- System integration and reconfigurability
- Miniaturization where appropriate
- Low-power operation
- Long-term operation

Summaries from the technology breakout sessions follow. More detailed results from the sessions can be found in Attachment E. The presentation of technologies here does not represent a prioritization or any evaluation other than that which occurred during the sessions themselves. Detailed technology assessments will be conducted post-workshop, as warranted.

1. Sample Management

The Sample Management group focused on technologies for maintaining organisms and obtaining physical samples. Discussion focused primarily on the last category, including the issue of sample storage and preservation. Sample management elements were defined as; sample preparation, manipulation, sample tagging, and processing/preservation. Of particular interest were technologies that help overcome one or more of the major challenges of space flight hardware design: volume, mass, power, and crew time constraints. The following are representative of the technologies identified:

- Programmable Digital Microfluidic Network (sample)
- Cryogenics (preserve)
- Technology for Preservation of Cell Samples by Avoiding Crystallization (preserve)
- Cooler on a Chip (preserve)
- CellCult Cassette (maintain)
- Microfabricated Responsive Drug Delivery (reagent storage)

In addition to specific technologies, a number of key issues were identified relevant to technology development and the associated science supported by the technologies. These issues are summarized below.

Technology Issues:

- Technology needs
 - Automated fixing and pre-processing system
 - A system to convert mRNA to cDNA inflight to increase stability
 - “SmartBaggie” concept for sample handling: flexible, supports containment, fluid pass through, imaging, and storage
 - Ability to create biosample stasis and preservation
 - Ability to extend the quality and quantity of biosample materials returned
- A flow cytometer has more value when combined with an adequate microscope

Science Issues:

- Cooling issues (freeze or freeze-dry) tend to be sample-specific
- Need to make samples available to more investigators
- Conduct ground and flight experiments to gather baseline data. Test simple technology/model organism systems that will support development of detailed experiment protocols. Baseline data will help focus future experiments.

2. Bioanalytical Technologies

The Bioanalytical group looked at the full range of sensing technologies, including detection of chemicals and gases required, quantitative cytometry, spectrometry, and spectroscopy tools. A key conclusion was that most of the necessary technologies already exist but that they require miniaturization, automation, and integration for autonomous *in situ* operation and that many will require adaptation for space flight. The following are representative of the technologies identified:

- Flow Cytometry
 - High speed
 - Miniaturized (in-situ, chip platforms)
- Chromatography (on microfluidic chip platforms)
 - Amplification (PCR - Polymerase Chain Reaction)
 - Purification
 - Filtration
 - Chemically-specific capture
 - Preconcentration
 - Reagent, sample distribution
- Detection Technologies (and other tools)
 - Blue, UV LEDs (Light-Emitting Diodes) and solid-state lasers
 - Integrated detection/measurement systems for chromatography-on-chip systems
 - Chemical and gas microsensors; optical, electrochemical, solid-state technologies, pH, RH, O₂, CO₂, NH₃, ions, and electronic noses
 - Electrical, electrophysiological measurements
 - Imaging (for integration with microsystems)
 - Automated biopsy system
 - Metal nanostructures templated by structural protein scaffolds
 - Computational fluid dynamics for design, simulation, prediction
- Microfluidic Components
 - Electrokinetic pumps
 - Integrated nanobore HPLC (High-Performance Liquid Chromatography) pumps
 - Centrifugal pumps on CD format disk
- Possible Application Focus Areas
 - Whole-cell assay, analysis
 - Fluorescent cell analysis/imaging
 - Gene expression
 - Genotyping (include sequencing, SNPs - Single-Nucleotide Polymorphism)
 - Protein expression, protein distributions
 - Proteomics
 - Cell populations; single cells

Technology Issues:

- Need to consider radiation effects on hardware function
- High-speed data downlink is a big hurdle for *in situ* measurements
- Integration issues
 - Preferable to combine multiple tests on a single sample, rather than process a new sample for each parameter
 - Need to integrate robust optics with microfluidics systems
- Microfluidics systems tend to be gravity independent. Surface tension takes over. May need minifluidics systems for small organisms such as *C. elegans* that are too

large for microfluidics. Some commercial mini systems may be appropriate, but at the mini scale gravity will begin to play a role in their operation.

- Stirring/shaking systems needed for flight environment
- Diagnostic systems suitable for crew measurements
- Video, imaging systems must be customized to the application and platform

Science Issues:

- For nematodes, need video, CO₂, O₂, NH₃, H₂O sensing, and the ability to pick out a single live organism from a group
- Need inflight diagnostics and environmental sensing
- Lysing (splitting open) cells: killing cells slowly may result in gene expression artifacts
- Need a full suite of chemical and biological sensors packaged in integrated systems
- Sampling statistics associated with microfluidic systems (for certain apps)
- Synergies and competitive effects of radiation and micro-gravity
- Measuring genetic adaptations in populations rather than individuals

3. Imaging/Photonics

The Imaging/Photonics group addressed a topic that is a mainstay of biological research. The field includes miniature cameras, microscopes, multi-spectral imaging, laser scanning, scanning probe techniques, NMR, IR, far-IR with color coding for visualization, and associated dyes, tags, and molecular markers. Technologies and related components emerging for imaging are wide-ranging and a multidisciplinary approach will be required for proper integration of imaging into technology systems.

Technology Issues:

- Some guidelines and high-priority needs for providing imaging technology in space:
 - System integration and automation of the imaging-support functions
 - Autofocus and autoexposure
 - Automatic sample loading and positioning
 - Machine vision tasks: object recognition and tracking
 - Data compression, transmission, and storage
 - Illumination control
- A major topic of discussion was the need for an optical compound microscope qualified for space flight. This issue also emerged in the Sample Management group, underscoring the importance of this topic for many investigators. The Imaging/Photonics group had the following recommendations for such a system:
 - Capability of 50X to 1000X optical microscopy is wanted by many
 - COTS form of this instrument is awkward and difficult to use in space. (Too many knobs to turn per image.)
 - Automatic, point-and-shoot operation, similar to a digital camera, combined with automatic sample loading and positioning

Science Issues:

- The most useful short-term addition would be an optical microscope in some configuration
- Need to clearly define scientific problems for more focused discussion of technology solutions

D. Strategic Vision and Technology Insertion Breakout Session

The fourth subgroup of the Technology Breakout Session, Strategic Planning/Management/Technology Insertion is presented here. The issues discussed fell under the three topics below.

1. Define Strategies for Developing a Technology Roadmap

- Identify and track emerging technologies at a Technology Readiness Level (TRL) of 5 (Breadboard Test) or above. Group technologies by TRL, as possible for prioritization.
 - Low-TRL: Outside NASA; Commercial, CSCs, DARPA, DOE, Univ. R&D
Inside NASA; Level I SBIR, STTR, OAT, OBPR
 - Mid-TRL: Inside NASA; Level II SBIR, STTR, CSCs
 - Hi-TRL: Inside NASA; Level III SBIR, STTT, Commercial, CSCs
- Track NASA cross-code technology to facilitate pooling of NASA needs/resources and link to commercial technology needs for leveraging co-development options
- Technology risks (unstable funding, platform-specificity) need to be minimized
- Do study and prepare plan on where technology investments are most needed, how to leverage development resources and best insert technologies. For example, there are no available *in situ* (on-orbit) measurement technologies available for FSB research.
- Develop a Technology Development Roadmap for presentation to ARC management, OBPR management, and to Code R, and include a definition of needs, schedule, costs, and benefits

2. Define Strategies for Technology Development & Insertion

- Establish a Code U “Technology Broker” to facilitate strategies in 1 above and help capture resources for co-development. Broker can help define common interests within NASA, other agencies, commercial entities, univ. R&D groups, etc..
- Establish a Technology Steering Committee within OBPR to track cross-Division technology needs and link to technology capabilities (see TechWatch developed by the AstroBionics IPT (astrobionics.arc.nasa.gov))
- Technology design goals should include low-cost, disposable biosample systems for flight and more complex, shared ground systems for data analysis. Define more clearly what science processes and operations are required inflight vs. on-ground. Develop generic, modular, integrated systems with replaceable subcomponents to minimize customization and re-verification costs.
- Hard to get high priority tech needs from NASA Enterprises. ARC Commercial Technology Office (CTO) and Technology Steering Group (see above) could help facilitate.

- Define at what point in the technology develop/insertion process leveraging and co-development will be most effective. Leveraging is focused on combining funds to develop a technology that is needed by two or more entities. Co-development is focused on combining funds and resources to develop a core technology that can be used for multiple purposes by two or more entities with additional customization.
- Need broad technology solutions, the rationale for which is support of OBPR research objectives. Advocate for integrated technology solutions to upper-level NASA management and show the value-added.
- Develop a Technology Roadmap that identifies customer(s) and facilitates research by community-directed technology development in addition to PI-directed development (peer-reviewed proposals)
- Team with commercial and university sectors to capture miniature (not micro), almost ready technology
- After defining NASA HQ hi-priority Enterprise needs, demonstrate clear value-added by appropriate technology to NASA's major objectives including; one NASA, Homeland Security, commercial co-development, biomedical applications/ countermeasures for human exploration of space, and education

3. Define Science/Technology Collaboration Options

- Post-workshop actions need to be scoped including implementation of science/technology focus groups, pilot study demonstrations, and collaborative team activities
- Science and operational requirements for flight payloads need definition to support development of detailed technology needs
- Science and mission scenarios for model organism research need to be further defined for each targeted platform to support identification of potential cross-platform technologies
- Further define technology systems for potential development including several identified at the workshop: systems to freeze/preserve/return biosamples & organisms; a sample management system; miniature, digital, automated *in situ* fluorescent microscopy systems; bioanalytical detection systems; and reference sensor systems

E. Science Scenarios Breakout Session

The second day's breakout sessions focused on the integrated payloads, systems, and experiment configurations needed for research with specific model organisms. The organisms were broken down into 1) Yeast/Bacteria/Mammalian Cells, 2) Nematodes/Fruit Flies, 3) Plants, and 4) Rodents/Humans.

The breakout groups were asked to consider the following questions:

- What science scenarios might be envisioned using these model organisms?
- How might they be enabled with the technologies identified in the earlier sessions?
- What would the experiment payload configuration be?

- What technologies/components does the payload require?
- What are the constraints and/or advantages of the proposed approaches?

The groups were asked to consider science and related technology requirements for each of the three reference flight platforms: ISS/Shuttle, Free Flyer, and Nanosatellite. Summaries from the four groups are provided below. More detailed results from the sessions can be found in Attachment E, including: science scenarios for each organism; platform applicability; and technologies needed for sample, analyze, and image.

1. Yeast/Bacteria/Mammalian Cells

Science Issues:

- Yeast
 - Large numbers of cells; need statistically valid subset of representative volumes from which measurements are made
 - Need clear information about clumping, adhesion, bubbles, etc. in μg to ensure the high-tech tools will work
 - Coulter-counter and flow-cytometry approaches highly desirable, but must work with 10^5 - 10^7 cells/ml densities
 - For “bulk” measurements (optical density, etc.), scattering may be a big issue
- Mammalian Cells
 - Big differences compared to yeast and bacteria are the culture conditions and need to separate different cell types in co-cultures
 - Potential greater relevance to human adaptation
 - For radiation effects, need to somehow separate out effects on individual cells from populations of cells?
- Bacteria
 - An under-valued model organism—can be genetically engineered, and has relevance in terms of pathogenicity (known changes in microgravity)
 - May require somewhat different sample preparation (as for some yeasts) due to cell wall composition

Technology Issues:

- What about freeze-drying cells instead of just freezing; need to show that mRNA (etc.) is preserved. Use very little energy to freeze quickly, then expose to vacuum and store under inert gas. Thereafter, requires no energy to preserve.
- Cells can and should be engineered to act as reporters—merge sensing with the organism. “Bioreporter” concepts need more evaluation.
- Tendency to focus on finding one “perfect” measurement tool. Need to consider multiple imperfect sensors, either of the same or different modalities, with good data fusion.

2. Nematodes/Fruit Flies

Science Issues:

- Make use of cutting-edge techniques that can be implemented pre-launch
 - Green Fluorescent Protein (GFP): monitor gene expression in live cells
 - RNA interference (RNAi): creates targeted gene knockouts
- Make use of rapid doubling/generational time to perform long-term adaptation experiments
 - Nematode: 50 generations a year
 - Fruit fly: 36-40 generations a year
- Make use of mutational techniques to increase selective pressure
 - Use HSP-90 mutants
 - Make gene duplications

Technology Issues:

- Nematodes
 - Imaging issues
 - Behavioral studies: want optical resolution of 12 microns per pixel (existing ability)
 - Fluorescent imaging of organ systems, 6 microns per pixel, prefer 2-3 microns per pixel
 - Want 17-25 °C inflight
 - Want sub-culturing ability: separate generations and developmental stages
 - Use removable sub-chambers with size-selective filters
 - Need data storage and high speed transmission
 - Could do PCR with microfluidics on pre-determined genes of interest
 - Would need to 'crack open' worms in flight: chemical lyse, sonic, heating or cooling, pressure, bead-beating/mechanical lysing
- Fruit Flies
 - Send up at 11.5 °C, need thermoelectric cooler and heat sink
 - Need 60-80% humidity; if system is closed enough, agar provides this
 - Oxygen source will be required; could use a generator like manganese dioxide
 - In the Insect Habitat for multi-generational studies, could some eggs be removed and preserved for analysis on Earth?
 - Visualization: for looking at structure, want about 60x magnification

3. Plants (Arabidopsis)

Science Issues:

- Are sensitive to moisture and nutrients levels
- Seeds are very small (less than 1 mm) and must be oriented properly in the soil to grow a root in the right direction
- Small size makes seed harvesting and replanting in space very difficult
- There has been successful seed-to-seed growth in space, but not routinely

- mRNA can be used to understand gene expression effects in microgravity
- Space effects on life support can be understood by monitoring the metabolic cycles
- Fibrous structure of plants reveals microgravity effects on anatomy useful to long-term space missions
- Destructive enzymes and phenols can begin to break down mRNA within seconds
- Soil matrices must be engineered for space; many issues with hydroponics, soil microbes, and water/nutrient infusion must be addressed

Technology Issues:

- Instrumentation Needs
 - Temperature of soil and air, Water content of soil and air (relative humidity), growth lighting spectrum, light/dark timing, duration, and intensity
 - Gas concentration and uptake (Primary: CO₂, O₂ (50-5000 ppm), C₂H₄ (100 ppb), Secondary: CH₄, NH₃, jasminate), plant weight: fresh & dry, Foliage morphology: area & structure (digital camera), soil ionics: K⁺, Na⁺, NO₃⁻, NO₂⁻, pH, optical properties of foliage: reflectance, fluorescence
- Analysis Needs
 - mRNA mapping: snip leaf, digest, separate, lyse, sequence (mainly microfluidics), Analysis of metabolic components: (Carbohydrates, sugars, ATP, NADH; Phenolic compounds (lignin), Nitrogen containing secondary compounds, Terpenes), Assays for specific proteins, Analysis of cellulose, lignin content
- Existing technologies can support most inflight instrumentation needs and constraints of volume, weight, and power. The primary challenge is integrating and automating the instrument package for ground-based control or minimizing crew effort.
- Biochemical analysis of plant tissues is the most challenging, and requires the development of flexible, mission-specific microfluidic systems
- Chemical analysis is sufficiently demanding to possibly justify spectrophotometers and mass spectrometers within the instrument package. This would offer more flexibility than the “one sensor per analyte” approach.

4. Rodents/Humans

Science Issues:

- Rodents allow for closer experimental comparisons to humans
- Organize and acquire ground-based knowledge needed to design prototype facilities for rodent mating, gestation (20 days), birthing, and rearing to weaning age (at least 20 days postpartum)
- Sense and observe animal and the natal environment in manner compatible with ground-based research
- Anticipate needs for rodent surgeries and dissections
- Preserve and store samples and specimens
- Return living rodent specimens
- Humans have significant overlap with rodents (both mammals) especially in areas of non-invasive and minimally-invasive technologies
- Humans ideally would have fewer biosamples taken over time with more data extracted per sample using miniaturized systems

Technology Issues:

- Requirements Inside Habitats
 - Environmental Sensors
 - Video (L/D)
 - Add AI to activate video and provide automated alerts
 - Kinematics to study activity over time
- Telemetry Requirements
 - Biophysical: pressure, force, temperature
 - Physiological: EKG, EEG, etc.
 - Biochemical: TBD
 - Stimulate/Deliver: implants to activate systems and deliver drugs
 - Inject markers
 - Add physical challenge
- In Vivo Monitoring
 - Tissue Labels
 - Fluorescent probes
- GPWS/Mounted
 - BioFlips (DARPA)
 - Wearable monitors: glucose, lactate, Na⁺, pO₂, pH
 - Microdiagnostics
 - Small samples
 - Gene expression
- General Requirements
 - Automate
 - Make efficient
 - Make capable
- Human Requirements
 - Continuous/non-invasive measures (breath, urine/feces, saliva, thru-skin measures, smart ear-plugs)
 - Technologies for making multiple measurements from very small samples taken over months

F. Recommendations

Recommendations generated throughout the course of the workshop are summarized below under the categories of technology, science, and program implementation.

1. Technology

- Aggressively pursue biosample preservation technologies and systems
 - More assessment needed of freezing options: snap freezing (<1 ml), quick-freezing (>1 ml), freeze-drying and chemical preservation. Track freezer development underway within NASA including: KSC for LN₂ Passive Freezers, and JSC for -80 deg C, -180 deg C Active Stirling Engine freezers

- Explore possibility of using vacuum of space and existing freezers to provide freeze drying capability
- Explore digital imaging, spectroscopy, and fluorescence systems
 - Need a microscope that is digital, software-driven, miniaturized, and can have lens integrated with the experiment, if needed
- Pursue biofluidics technologies for autonomous *in-situ* mission profiles
- Focus on a significant reduction of ISS crew time as currently projected for research, through the use of automated, miniaturized systems
- Encourage high-speed, high-bandwidth data downlink transmission capabilities for both Free Flyers and ISS
- Investigate use of integrated technologies for sample management and retrieval
- Conduct early functionality flight testing of new technologies in the space environment
- Create a payload demonstration and test bed capability by conducting a model experiment using emerging SSBRP science evaluation hardware that showcases new technology. Show what could be accomplished within existing and emerging ISS habitats augmented by advanced technologies.

2. Science

- Develop guidelines for statistically valid sampling of representative biosample volumes to ensure science validity
- Prove “novel” new technology measurement methods against lab standards
- Help better characterize existing habitats to separate equipment artifacts from space flight effects
- Maximize science opportunities by optimizing biosample and data sharing

3. Implementation

- Investigate passive (no upmass resource requirements) payload carriers and instruments for ISS Assembly-era flights
- Closely link strategic technology development activity to manned space flight and human exploration thrusts (see OBPR Strategic Vision), especially in relation to NASA's Biomedical Research & Countermeasures Program (<http://spaceresearch.gov/researchprojects/biomedical.lit.html>)
 - Use Life Sciences Data Archive (LSDA), NSBRI, and Critical Path (CP) database to link FSB publications to CP questions showing what has been accomplished. This will identify opportunities available to support Human Exploration and help define products that can come from new technology.
- Rapidly demonstrate available technology elements and breadboard integrated systems to demonstrate the value-added
- Continue to leverage external technology development to the benefit of FSB research
- Continue to ensure science is the central driver for FSB technology development
- Emphasize low-barrier access to space (e.g., modular and reconfigurable middeck locker packages, nanosats, etc.) to serve as a major force multiplier for early stage space biology technologies and pilot studies

- Institutionalize the interdisciplinary, interagency brainstorming format demonstrated in the workshop
- Continue implementing Techwatch, Focus Groups, and Science/Technology Collaborative Teams to define/compile requirements, assess technologies, assign priorities, and form collaborative technology development teams
- Form a high-level advisory body for FSB and OBPR-wide technology development

G. Conclusion

The T4FSB workshop provided a unique opportunity for scientists and engineers to exchange information and ideas about technology needs and capabilities, and generated fresh views on the fundamental assumptions and scientific drivers for missions. Enthusiasm was expressed by many attendees for the significant knowledge gained at the workshop. Participants identified miniaturized, modular, automated and retaskable instrumentation candidates for space biology research. They conceptualized new smart systems for preprogrammed and modifiable-on-the-fly experiments.

The workshop showed that NASA space research can benefit greatly from R&D in the commercial sector and that similar requirements to NASA's exist especially in the health and defense sectors. These requirements including miniaturization, automation and modularity will allow leveraging and co-development projects to be conducted. Representatives of the biotechnology community also indicated their strong interest in participating in post-workshop FSB activities.

Next steps will include further definition of science and operational requirements for translation into detailed technology needs. More detailed definition of experiment scenarios will be done using model organisms within a middeck locker payload element on each of the targeted platforms—ISS, Free Flyers, and nanosatellites. This work will be conducted in focus groups organized around specific technologies and science applications. Collaborative teams will further define technologies and methods of leveraging and co-developing them to minimize costs for each participating organization.

A Fundamental Space Biology Technology Roadmap will be developed further to guide targeted technology development and insertion. (A preliminary roadmap diagram, developed post-workshop by the event coordinators, is presented in Attachment F.) With management support and sufficient resources, the advanced technologies identified during this highly interactive science and engineering process will make a significant impact on supporting NASA, OBPR, and especially FSB mission and program objectives.

Attachment A: Agenda

Tuesday, October 22, 2002

New Biology Symposium/Tutorial

1:00PM-1:05PM	Welcome/Introduction	John Hines/Greg Kovacs
1:05PM- 2:05PM	The Basic Processes of Life The Big Picture; Working Vocabulary	Craig Heller
2:10PM- 3:10PM	Chemical and Biological Sensors - Technologies and Key Issues Relationship to Future Diagnostics	Greg Kovacs
3:35PM- 4:05PM	Separation and Biofluidics Technologies	Rich Mathies
4:10PM- 4:40PM	Advanced Photonic Technologies	Henryk Malak
4:45PM- 5:15PM	Design Considerations for Microfluidics in Space	Don Verlee
5:20PM- 5:50PM	Scaling Pros and Cons Miniaturization of Biological and Biomedical Devices, Technologies and Issues	Greg Kovacs
6:00PM-9:00PM	Workshop Welcome Reception/Registration	

Wednesday, October 23, 2002

Technology Workshop

8:30AM-9:00AM	Introduction	John Hines
9:00AM-9:30AM	Welcome/Introduction	Estelle Condon/Bob McElroy
	Goals and Intent of Workshop	John Hines
	Workshop Logistics	Julianna Fishman
9:30AM-10:30AM	Overview of Program	John Hines, et al.

Wednesday, October 23, 2002, continued

	Objectives Science Objectives	Charles Wade
	Mission Options	Gary Jahns
	Technology Drivers and Needs	John Hines
11:00AM-11:30AM	Technology Trends and Drivers	Greg Kovacs
11:35AM-11:50AM	Summarize Scope of Tutorial	Greg Kovacs/Tony Ricco/John Hines
11:55AM-12:05PM	Charge to Breakout Groups	John Hines
1:20PM-3:30PM	Breakout Session I - Applicable Technologies (components)	Facilitators
	1. Sample Management	Don Verlee/Greg Kovacs
	2. Bioanalytical Technologies	Tony Ricco/TBD
	3. Imaging/Photonics	Milan Mrksich/ Robert Darling
	4. Strategic Planning, Management, Technology Insertion	John Hines/ Greg Schmidt
4:15PM-6:00PM	15-min summaries from Groups 1-4	

Thursday, October 24, 2002

7:45AM- 8:30AM	Continental Breakfast	
8:00AM-8:10AM	Welcome	Greg Kovacs/ Tony Ricco/ John Hines
8:15AM-9:00AM	Discussion of Prior Day Breakout Session	
9:00AM-10:15AM	Breakout Session II – Model Organisms 1. <i>S. cerevisiae</i> Bacteria/ Mammalian Cells	Facilitators Greg Kovacs/Paul Todd

Thursday, October 24, 2002, continued

	2. <i>C. elegans</i> / <i>Drosophila Melanogaster</i>	Tony Ricco/ Catherine Conley
	3. <i>Arabidopsis</i>	Robert Darling/ Gerard Heyenga
	4. Rodents/Humans	Michael Krihak/ Jeffrey Alberts
10:30AM-11:15AM	Breakout Session II continued	
11:15AM-12:15PM	15 min Summaries from Groups 1-4	
1:30PM-3:00PM	General Discussion	John Hines
3:30PM-5:00PM	Define, Prioritize Suggested Investment Strategy	John Hines
5:10PM	Formal Meeting Adjourns	
6:00PM-9:00PM	Workshop Staff - Review Workshop Content for Preparation of Final Report	

Attachment B: Biographical Sketches of Coordinators

John Hines

John Hines is Manager of the Biomolecular Systems Research Program, a collaborative Research and Technology Program between NASA and the National Cancer Institute, and Senior Technology Program Manager for the Fundamental Space Biology Program, which leads NASA's efforts in Space Biology Research. John is also the principal investigator/technologist for Advanced Biosensor Technology Development and Smart Healthcare Monitoring Systems, both of which are directed toward developing and applying next generation sensors, biotelemetry and measurement systems for Bioastronautics and Human Exploration applications. He is also a technology advisor/consultant/researcher for several DoD and DARPA programs.

Most recently, he has created and initiated the Astrobionics Integrated Program and Project Team (IPPT) at NASA Ames Research Center, to facilitate advanced biological and biomedical technology development for the NASA Office of Biological and Physical Research. He has a BS in Electrical Engineering from Tuskegee University, and a MS in Biomedical and Electrical Engineering from Stanford University, and has over 27 years of combined NASA and Air Force experience in biological and biomedical technology development, project management, engineering, and Life Sciences Spaceflight hardware development.

Gregory Kovacs

Gregory Kovacs received the B.A.Sc. degree in Electrical Engineering from the University of British Columbia, the M.S. degree in Bioengineering from the University of California, Berkeley, and the Ph.D. (EE) and M.D. from Stanford University. His industry experience includes the design of a wide variety of electronic instruments and biomedical systems, extensive Intellectual Property consulting, and co-founding of several companies (most recently Cepheid, Inc. [CPHD], in Sunnyvale, CA). He serves on the scientific advisory boards of several companies. He is an Associate Professor of Electrical Engineering at Stanford with an appointment in the Department of Medicine, by courtesy. He teaches courses in electronic circuits, microsystems, and biomedical technologies.

He received an NSF Young Investigator Award, held the Noyce Family Faculty Scholar Chair, was a Terman Fellow and University Fellow at Stanford, and has served as member and chair of the Defense Sciences Research Council (DARPA). His present research areas include biomedical instruments and sensors, miniaturized spaceflight hardware, biotechnology, and micro-scale devices, all with emphasis on solving practical problems. He has published extensively in the technical literature, including authorship of a popular engineering textbook, as well as obtaining a number of patents.

Antonio J. Ricco

Antonio J. Ricco is Sr. Director of Microtechnologies and Materials at ACLARA BioSciences. He received a BS and PhD in Chemistry from the University of California at Berkeley (1980) and the Massachusetts Institute of Technology (1984), respectively. He was a member of the Sandia National Laboratory Microsensor R&D Department from 1984 – 1998, focusing on chemical microsensor systems utilizing acoustic wave, optical, micromachined, electrochemical, and electronic platforms. In 1999 he joined ACLARA BioSciences, where his group develops core technologies for the commercialization of single-use plastic microfluidic array systems for bioanalytical applications, particularly genetic analysis, high-throughput pharmaceutical discovery, and proteomics. He is the co-author of over 200 presentations, 140 publications, and a dozen patents. He is a past Chair of the Sensor Division of The Electrochemical Society, a Fellow of The Electrochemical Society, and a recipient of the Sensor Division's Outstanding Achievement Award. With Professor Richard Crooks, he cofounded the *Gordon Research Conference on Chemical Sensors and Interfacial Design*. He served on the Editorial Advisory Board of *Analytical Chemistry* and is presently an Associate Editor of the *Journal of Microelectromechanical Systems* and the *Sensors Update* series. He is a past chair (1998) of the Hilton Head Workshop on Solid-State Sensors, Actuators, and Microsystems and a trustee of the Transducers Research Foundation.

Attachment C: Attendee List

Jeff Alberts

Indiana University
Department of Psychology
Bloomington Indiana 47405
Phone: (812) 855-3309
Email: alberts@indiana.edu
Animal Behavior and Development

Duncan Atchison

Lockheed Martin
NASA Ames Research Center
Mail Stop 240A-4
Moffett Field CA 94035
Phone: (650) 604-2144
Email: datchison@mail.arc.nasa.gov

Leonidas Bachas

University of Kentucky
Lexington KY 40506-0055
Phone: (859) 257-6350
Email: bachas@uky.edu
Analytical/Bioanalytical Chemistry

C. Fred Battrell

Micronics, Inc.
8463 154th Av NE
Redmond WA 98052
Phone: (425) 895-9197 x102
Email: fbattrell@micronics.net
Microfluidics

Shirley Berthold

Lockheed Martin
NASA Ames Research Center
Building 244, Room 150
Moffett Field CA 94035
Phone: (650) 604-1654
Email: sberthold@mail.arc.nasa.gov

Linda Andrews

NASA Ames Research Center
Mail Stop T35B-1
Moffett Field 94035
Phone: (650) 604-6183
Email: landrews@mail.arc.nasa.gov
Information Management Technology

Leon Avery

Dartmouth College
C. elegans

Valerie Barker

Stanford University
Building CISX 218X
330 Serra Mall
Stanford CA 94305
Phone: (650) 723-5646
Email: vbarker@sensors.stanford.edu
Mechanical Engineer

Gregory Bearman

Jet Propulsion Laboratory/NASA
4800 Oak Grove Drive
Pasadena, CA 91109
Phone: (818) 354-3285
Email: gbearman@jpl.nasa.gov
Biological Spectroscopy and Imaging

Sharmila Bhattacharya

NASA Ames Research Center
Mail Stop T20G-2
Moffett Field CA 94035
Phone: (650) 604 1531
Email: sbhattacharya@mail.arc.nasa.gov
Drosophila, Yeast, Molecular Biology, Genetics

Carolina Blake

Lockheed Martin
NASA Ames Research Center
Building 202, Room 211B
Moffett Field CA 94035
Phone: (650) 604-0893
Email: cblake@mail.arc.nasa.gov

Rita Briggs

Lockheed Martin
NASA Ames Research Center
Moffett Field CA 94035
Phone: (650)-604-1015
Email: rbriggs@mail.arc.nasa.gov

Estelle Condon

NASA Ames Research Center
Moffett Field CA 94035
Phone: (650)-604-6071
Email: econdon@mail.arc.nasa.gov

Kathleen Connell

NASA Ames Research Center
Mail Stop 244-10
Moffett Field CA 94035
Phone: (650)-604-4837
Email: kconnell@mail.arc.nasa.gov

Bonnie Dalton

NASA Ames Research Center
Mail Stop 200-7
Moffett Field CA 94035
Phone: (650) 604-6188
Email: bdalton@mail.arc.nasa.gov

Joe Dardano

Email: Joe.dardano.lmco.com

Richard Boyle

NASA Ames Research Center
Mail Stop 239-11
Moffett Field CA 94035
Phone: (650) 604-1099
Email: rboyle@mail.arc.nasa.gov
Neurosciences

Elizabeth Cantwell

Lawrence Livermore National Lab
7000 East Avenue
Livermore CA 94550
Phone: (925) 424-2687
Email: cantwell1@llnl.gov
Technology

Catherine Conley

NASA Ames Research Center
Mail Stop 239-11
Moffett Field CA 94035
Phone: (650) 604-1099
Email: cconley@mail.arc.nasa.gov
C. elegans-Growth and Regulation of Development

David Cooper

SRI International
333 Ravenswood Avenue
Menlo Park CA 94025
Phone: 650-859-3742
Email: david.cooper@sri.com
Upconverting Phosphors

Michael Daly

Uniformed Services University of Health Services
4301 Jones Bridge Road
Bethesda MD 20814
Phone: 301-295-3750
Email: Mdaly@usuhs.mil
Deinococcus radiodurans

Robert Bruce Darling

University of Washington
Dept. of Electrical Engineering
Box 352500
Seattle WA 98195-2500
Phone: (206) 543-4703
Email: bdarling@ee.washington.edu

Minoo Dastoor

NASA Headquarters
Email: mdastoor@mail.hq.nasa.gov

Phil Davies

Lockheed Martin
Ames Research Center
Mail Stop 19-20
Moffett Field CA 94035
Phone: (650)-604-3608
Email: pdavies@mail.arc.nasa.gov

Mark Deuser

SHOT
7200 Highway 150
Greenville, IN 47124
Phone: (812) 923-9591 ex247
Email: mdeuser@shot.com
Flight Hardware Development

David Engelbert

San Jose State University
Mail Stop 19-4
Moffett Field CA 94035
Phone: (650) 604-3964
Email: dengelbert@mail.arc.nasa.gov
Technology

Guy Etheridge

NASA- KSC
YA-E4
Kennedy Space Center FL 32899
Phone: (321) 867-6369
Email: guy.etheridge-1@ksc.nasa.gov
Flight Hardware

Michael Flynn

NASA Ames Research Center
Mail Stop 239-15
Moffett Field CA 94035
Phone: (650) 604-1163
Email: mflynn@mail.arc.nasa.gov

Paul Fung

NASA Ames Research Center
Mail Stop 19-20
Moffett Field CA 94035
Phone: (650) 604-1276
Email: pfung@mail.arc.nasa.gov

Kristin Gilchrist

Stanford University
CIS 218X
Stanford CA 94305
Phone: (650) 723-5646
Email: krh@stanford.edu
Biosensors

Laurent Giovangrandi

Stanford University
Center for Integrated Systems
420 Via Ortega, Room 218X
Stanford CA 94305
Phone: (650) 723-5646
Email: giovan@stanford.edu

Mario Goins

AstroBionics IPT
NASA Ames Research Center
Mail Stop 213-2
Moffett Field CA 95036
Phone: (650) 604-1403
Email: mgoins@mail.arc.nasa.gov

Steve Gonda

NASA/Johnson Space Center
2101 NASA Road 1
Mailcode SJ
Houston TX 77058
Phone: (281) 483-8745
Email: steven.gonda1@jsc.nasa.gov

James Harris

Gerard Heyenga

BioServe Space Technologies/University of
Colorado
NASA Ames Research Center
Mail Stop 239-23
Moffett Field CA 94035
Phone: (650) 604-6725
Email: gheyenga@mail.arc.nasa.gov
Plant Growth and Development in Space

John Hines

NASA Ames Research Center
Mail Stop 19-20
Moffett Field CA 95035
Phone: (650) 604-5538
Email: jhines@mail.arc.nasa.gov
Biological Technologies

Gary Jahns

NASA Ames Research Center
Mail Stop 19-20
Moffett Field CA 94035
Phone: (650) 604-6596
Email: gjahns@mail.arc.nasa.gov

Antony Jeevarajan

Wyle Laboratories/NASA JSC
1290 Hercules Dr. Suite 120
Mail Stop BT-37
Houston TX 77058
Phone: (281) 483-4298
Email: ajeevarajan@ems.jsc.nasa.gov
Sensors and Controls for Bioreactors

Chuck Jorgensen

NASA Ames Neuro Engineering Lab
Mail Stop 269-1
Moffett Field CA 94035
Phone: (650) 604-6725
Email: cjorgensen@mail.arc.nasa.gov
Neuro Network Computing

Ali Kashani

NASA Ames Research Center
Mail Stop 244-10
Moffett Field CA 94035
Phone: (650) 604-6534
Email: akashani@mail.arc.nasa.gov
Cryogenics

Chang-Jin (CJ) Kim

UCLA
38-137, E4, MAE Dept.
420 Westwood Plaza
Los Angeles Ca 90095
Phone: (310) 206-8719
Email: cjkim@ucla.edu
Microfluidics

Gregory Kintz

Cepheid
904 Caribbean Drive
Sunnyvale CA 94089-1189
Phone: (408) 400-8293
Email: kintz@cepheid.com
Photonics

Peter Kittel

NASA Ames Research Center
Mail Stop 244-10
Moffett Field CA 94035-1000
Phone: (650) 604-4297
Email: pkittel@mail.arc.nasa.gov
Cryogenics

John Kizito

NASA Glenn Research Center
2100 Brookpark Road
Cleveland OH 44135
Phone: (216) 433-8000
Email: John.P.Kizito@grc.nasa.gov
Microfluidics in Space

Kenneth Kosik

Harvard Medical School
77 Ave Louis Pasteur
Boston MA 02115
Phone: (617) 525-5230
Email: kosik@bwh.harvard.edu
Genomics

Greg Kovacs

Stanford/AMES Research Center
CISX-202
Stanford CA 94305-4075
Phone: (650) 725-3637
Email: kovacs@cis.stanford.edu
Biosensors/Systems

Michael Krihak

DARPA
3071 N. Fairfax Drive
Arlington VA 22203
Phone: (571) 218-4246
Email: mkrihak@darpa.mil

Peter Krulevitch

Lawrence Livermore National Laboratory
P.O. Box 808, L-222
Livermore CA 94551
Phone (925) 422-9195
Email: krul@llnl.gov
Microfabrication and Materials

Dirk Lange

Stanford University
CIS-205X
Stanford CA 94305
Phone: (650) 725-6139
Email: dirk.lange@stanford.edu
Sensors and Systems

James Leary

301 University Blvd.
Galveston Texas 77555-0130
Phone: (409) 747-0547
Email: jleary@utmb.edu
Nanomedicine/High Throughput Cell Separation

Greg Leonard

Mains Associates
2039 Shattuck Ave.
Suite 506
Berkeley CA 94704
Phone: (510) 548-1262
Email: gleonard@mainsgate.com
Science Communications

Ofer Levi

Stanford University
SCIS-X room 310
Stanford CA 94305
Phone: 1-650-725-6907
Email: levi@snowmass.stanford.edu
Optical Devices

Miss Janice Li

Stanford University
CIS-205X
420 Via Ortega
Stanford CA 94305
Phone: (408) 725-6139
Email: jjli@stanford.edu

Dorian Liepmann

UC Berkeley
Dept. of Bioengineering
463 Evans Hall
Berkeley CA 94720-1762
Phone: (510) 642-9360
Email: liepmann@me.berkeley.edu

Bob MacElroy

NASA Ames Research Center
Mail Stop 19-20
Moffett Field CA 94035
Phone: (650) 604-5573
Email: rmacelroy@mail.arc.nasa.gov

Richard Mains

Mains Associates
2039 Shattuck Ave.
Suite 506
Berkeley CA 94704
Phone: (510) 548-1262
Email: rmains@mainsgate.com
Space Biology and Communications

Henryk Malak

University of Maryland
8444 High Ridge Road
Ellicott City MD 21043
Phone: (410) 313-8650
Email: henrykmalak@comcast.net
Photonics

Nadim Maluf

New Focus
2584 Junction Rd
San Jose CA 95134
Phone: (408) 919 2711
Email: nmaluf@newfocus.com

Raymond Mariella

LLNL
Center Director for Microtechnology
7000 East Ave. L-222 P.O. Box 808 L-222
Livermore CA 94551
Phone: (925) 422-8905
Email: mariella1@llnl.gov

Fred Martwick

NASA Ames Research Center
M/S 213-4
Moffett Field CA 94035
Phone: (650) 604-3758
Email: fmartwick@mail.arc.nasa.gov

Kimberly May

University of Kentucky
127 Seale Avenue
Palo Alto CA 94301
Phone: (650) 604-1723
Email: kmmay0@uky.edu

John McGrath

University of Arizona
P.O. Box 210119
1130 N. Mountain
Tucson AZ 85721
Email: mcgrath@engr.arizona.edu

John Meador

Medtronic
Email: john.meador@medtronic.com

Deirdre Meldrum

University of Washington
Department of Electrical Engineering
Box 352500 Seattle WA 98195-2500
Phone: (206) 685-7639
Email: deedee@ee.washington.edu
Miniaturized Biotech

Carlo Montemagno

University of California
7523 Boelter Hall
Los Angeles CA
Email: cdm@seas.ucla.edu
BioNano

Milan Mrkshich

University of Chicago
5735 South Ellis Avenue
Chicago, IL 60637
Phone: (773) 702-1651
Email: mmrksich@midway.uchicago.edu

David Niesel

University of Texas Medical Branch
301 University Blvd.
Galveston TX
Email: dniesel@utmb.edu
Genomics/Proteomics

Mary Noke

Email: marynoke@yahoo.com

Mark Ott

EASI/Wyle Laboratories
1290 Hercules Drive
Houston TX 77058
Email: charlie.m.ott1@jsc.nasa.gov

Matt Ottenberg

DakoCytomation
4850 Innovation Drive
Fort Collins CO 80528
Phone: (970) 226-2200
Email: matt.ottenberg@dakocytomation.com
Cytometry

Phillip Paul

Eksigent Technologies
Email: phpaul@eksigent.com
HPLC on a Chip

Michael Pecaut

Loma Linda University
Dept. of Radiation Medicine (Radiobiology Program)
1175 Campus St. CSP A-1010
Phone: (909) 558-5379
Email: mpecaut@dominion.llumc.edu

Ryszard Pisarski

Commercial Technology Office
NASA Ames Research Center
Mail Stop 202A-3
Moffett Field CA 94035
Phone: (650) 604-0149
Email: rpisarski@mail.arc.nasa.gov

Ross Ramos

Lockheed Martin
NASA Ames Research Center
Mail Stop T20G-2
Moffett Field CA 94035
Phone: (650) 604-6509
Email: raramos@mail.arc.nasa.gov

Sharon Reynolds

Mains Associates
2039 Shattuck Avenue Ste. 506
Berkeley CA 94704
Phone: (510) 548-1262
Email: sreynolds@mainsgate.com
Drosophila/Genetics

Tony Ricco

ACLARA BioSciences
1288 Pear Ave.
Mountain View CA 94043
Phone: (650) 210-1241
Email: ajricco@attbi.com
Microbiology/Sensors

Marina Saltman

NASA Ames Research Center
Moffett Field CA 94035
Phone: (650) 604-4438
Email: msaltman@mail.arc.nasa.gov
Consultant

Robert Saltman

Email: rpsaltman@aol.com
Chemical Physics/Materials Science

Orlando Santos

NASA Ames Research Center
Mail Stop 19-20
Moffett Field CA 94035
Phone: (650) 604-1968
Email: osantos@mail.arc.nasa.gov

Ronald Schaefer

Lockheed Martin: ARC
NASA Ames Research Center
MS 236-5
Moffett Field CA 94035
Phone: (650) 604-4438
Email: rlshaefer@mail.arc.nasa.gov

Greg Schmidt

NASA Ames Research Center
Mail Stop 200-7
Moffett Field CA 94035
Phone: (650) 604-2611
Email: gschmidt@mail.arc.nasa.gov

Nancy Searby

NASA Ames Research Center
Moffett Field CA 94035
Phone: (650) 604-6794
Email: nsearby@mail.arc.nasa.gov
Cytoskeleton, Cell Cultures

Michael Sims

PO Box 371176
Mellon Institute Room 292
Montara, PA 94037
Phone: (650) 604-4757
Email: Michael.Sims@arc.nasa.gov

Alison Skelley

Email: alison@zinc.cchem.berkeley.edu

Jeffrey Smith

NASA Ames Research Center
MS 239-11
Moffett Field CA 94035
Phone: (650) 604-2586
Email: jdsmith@mail.arc.nasa.gov
Computer Science

Ken Souza

Girvan Institute of Technology
NASA Ames Research Park
Mail Stop 19-46
Mountain View CA 94035
Phone: (650) 604-5736
Email: ksouza@mail.arc.nasa.gov
Space Biology, Project Management

Viktor Stolz

NASA Ames Research Center
Mail Stop 229-4
Moffett Field CA 94035
Phone: (650) 604-0018
Email: vstolz@mail.arc.nasa.gov
Yeast, Molecular Biology

James Trebes

Lawrence Livermore National Laboratory
7000 East Ave.
Livermore CA 94551
Phone: (925) 423-7413
Email: trebes1@llnl.gov
Medical Physics

Luke Sing

SL/Lockheed Martin
Mail Stop N240A
P.O. Box 168
Moffett Field CA 94035
Phone: (650) 604-0549
Email: lsing@mail.arc.nasa.gov
Lead Engineer

Mike Skidmore

NASA Ames Research Center
Life Sciences Division
MS239-11
Moffett Field CA 94035
Phone: (650) 604-6069
Email: mskidmore@mail.arc.nasa.gov
Project Management

Rosemary Smith

University of California, Davis
Email: smith@ece.ucdavis.edu
Miniaturization

Ken Stirbl

NASA Jet Propulsion Laboratory/Cal Tech
4800 Oak Grove Drive
Pasadena CA 91101
Email: robert.C.Stirbl@jpl.nasa.gov

Paul Todd

SHOT, Inc.
7200 Highway 150
Greenville IN 47124
Phone: (206) 685-7639
Email: ptodd@shot.com
Cell, Liquid/Gas in Space, Flight Hardware Development

Jonathan Trent

NASA Ames Research Center
Mail Stop 239-15
Moffett Field CA 94035
Phone: (650) 604-3686
Email: jtrent@mail.arc.nasa.gov
Extremophiles

Don Verlee

MicroFluidic Systems Research
1109 Pine Tree Lane
Libertyville, IL 60048-2566
Phone: (847) 494-9557
Email: verleed@worldnet.att.net
Microfluidics

Victor Weedn

Carnegie Mellon University
4400 Fifth Avenue
Mellon Institute Room 292
Pittsburgh, PA 15213-2683
Phone: (412) 268-6250
Email: weedn@cmu.edu

Bruce Yost

NASA Ames Research Center
Mail Stop 239-20
Mountain View CA 94035
Phone: (650) 604-3543
Email: byost@mail.arc.nasa.gov

Jim Zoval

University of California, Irvine
21361 Kirkwall Lane
Lake Forest CA 92630
Phone: (949) 824-8515
Email: jzoval@uci.edu
Biomems Nanotechnology

Charles Wade

NASA Ames Research Center
Mail Stop 239-11
Mountain View CA 94035
Phone: (650) 604-3943
Email: cwade@mail.arc.nasa.gov
Human and Rodent Physiology, Muscle Physiology

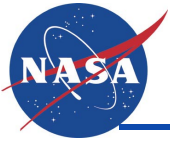
Richard Wisniewski

NASA Ames Research Center
Mail Stop 239-23
Phone: (650) 604-1024
Email: rwisniewski@mail.arc.nasa.gov
Biotechnology

Bob Zimmerman

NASA Ames Research Center
Mail Stop 210-8
Mountain View CA 94035
Phone: (650) 604-3656
Email: rzimmerman@mail.arc.nasa.gov
Technology Policy

Attachment D: Example Quad Charts

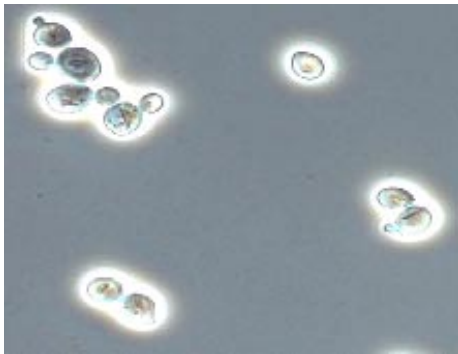


Saccharomyces cerevisiae for Space Studies Fundamental Space Biology Program Office, NASA-Ames

Fundamental Space Biology: Model Organisms

Goal

- Utilize Yeast (*Saccharomyces cerevisiae*) to investigate how microgravity affects growth rate and to determine DNA damage and repair response to space radiation.



Yeast 5-12 μ m

Approach

- Grow
- Sense
- Observe
- Analyze
- Preserve/Store

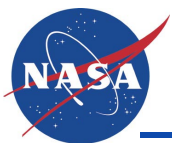
Significance

NASA has been involved in space biology research for decades with the intent of enabling exploration and long-term human habitation beyond our planet of origin. Now, with the knowledge from the genome projects of the major model organisms, and accompanying rapid development of new technologies, NASA's research program can provide new insights with application to human exploration. The humble baker's yeast *Saccharomyces cerevisiae* offers particular advantages for assessing human risk during space flight. Not only is it a good model organism for studies in cell structure, cell cycle, aging, and DNA mutation/repair mechanisms but it has attributes which makes it very suitable for space flight. It is robust, easy to handle (spores), rapid cell division (~ 2 hrs), easy to image (low mobility) and can be grown in an oxygen-free environment.

Technology Requirements

- Autonomous, miniaturized, integrated bio-lab able to withstand spaceflight and with the following basic elements:
 - Syringe microfluidics
 - Biosensors: pH, optical density, pressure, temperature
 - Temperature control
 - Dilution capability
 - Mixing capability
 - Oxygen/Carbon dioxide control
 - Advanced Optics: fluorescent microscope/flow cytometer
 - Sample management and preservation

Example Only

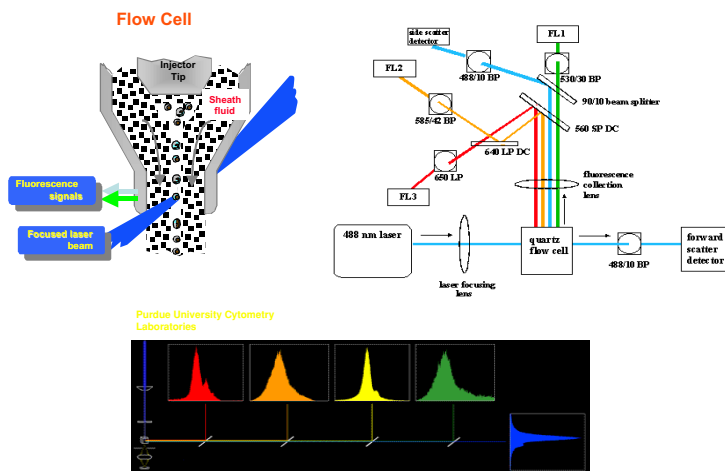


In-situ Cell Flow Cytometry/FACS

John Hines, NASA-Ames

Technology for Fundamental Space Biology

In-situ Cell Flow Cytometer



Description

Flow cytometers measure a single particle or 'event' in a field of flow as it passes through a beam of light. The light used can span the ultraviolet, visible or near infrared electromagnetic spectrum whose various wavelengths are scattered, absorbed, or emitted by molecules, macromolecular assemblies, cells, tissues, and polymer materials. Spectral information is obtained from each event at the moment of its passage in the beam), and multiple parameters can be measured simultaneously (count, size, granularity autofluorescence volume, fluorescence emissions of resident and/or applied fluorophores) at the single cell level.

NASA Significance / Innovation

Flow cytometry has applicability for space biological research as well as medical applications such as clinical diagnosis and health monitoring. Long duration space travel and habitation by humans and other biological species necessitates a fundamental understanding of the effects of weightlessness, radiation, and enclosed environments on their biology, and developing appropriate countermeasures. To study *in situ* space biology requires technologies constrained by low power, low weight, small volume, and fluidic systems that are compatible with microgravity.

Technology Development Challenges

- Miniaturization
- Power consumption
- Multicolor/multiparameter fluorescent excitation/detection
- Accuracy
- Stability
- sensitivity
- Sample prep, insertion, manipulation
- biofouling

Example Only

Attachment E: Session I & II Worksheets

Session I Group Name: Sample Management

Technology Name	Technology Details (Abbreviated)	Technology Hurdles (Abbreviated)
Microcytometry System – Cell/Particle Characterization	<ul style="list-style-type: none"> - White blood cell detection - Lysing of red blood on card - Electronic focusing of cytometer core - Cards have flow sensors and reagents - Two different pumping techniques 	<ul style="list-style-type: none"> - Stability - Air bubble management in microcircuit - Power consumption - System diagnostics - Sample interface - Reagent storage
Programmable Digital Microfluidic Network	<ul style="list-style-type: none"> - Electrically digitize the system to move drops - Reprogrammable - No need for physical channels; droplets follow active pads determined electrically - Has extremely low power consumption. 	<ul style="list-style-type: none"> - Fouling of surface with biofluids - Surface degradation over extended time and high temperature - Reliable coating of very thin hydrophobic layers - Repeatability of droplet size for creation and division - Packaging
Cryogenics	<ul style="list-style-type: none"> - Smallest now: 3 W cooling for 50 W input power - No flight cooler now small enough for NanoSat - Is there a way to vent to space? - Can we quick freeze with a Peltier device, vent to space, and still recover mRNA? Key: need access to space vacuum or a vacuum pump. 	<ul style="list-style-type: none"> - Power consumption - Miniaturization - Automation - Temperature stability - Cooling rate - Thermal contact between sample and cooler - Sample prep, insertion, manipulation - Reliability - Cost
Technology for Preservation of Cell Samples by Avoiding Crystallization	<ul style="list-style-type: none"> - Integration with sample handling could lead to autonomous processing - The idea is to avoid sample damage by crystallization. - Vitrification is an option: adding chemicals - Development should not be limited to “snap” freezers. 	<ul style="list-style-type: none"> - Need design specifications from biologists; will use these to design appropriate devices and processes for various species and flight platforms. - Currently, will get non-uniform freezing rates in normal sample size

CellCult Cassette	<ul style="list-style-type: none"> - Flew on STS-95, single vessel reactor - 50 ml reactor, or low-volume 8-10 ml cultures; one cassette has an entire laboratory. - Fits in middeck locker - Samples can be fixed inflight. - Uses spacecraft power, three cassettes in one middeck locker. If cooling is needed, that uses all 130 W available. 	<ul style="list-style-type: none"> - Add microscope, pH, DO, glucose monitoring + control - Gain more access to space flight - Could be compatible with ISS if funding available
Cooler on a Chip	<ul style="list-style-type: none"> - Joule-Thompson coolers are commercially available, etched into a glass microscope slide - These could be used in a fluidics circuit 	<ul style="list-style-type: none"> - Suitable flight qualified compressors do not exist to circulate the working fluid within the cooler
Microfabricated Responsive Drug Delivery	<ul style="list-style-type: none"> - Microvials would release drugs into the body; controlled by chemical sensors - Valving options: <ul style="list-style-type: none"> Microvials An electroactive hydrogel Protein immobilized within a hydrogel - How to go about storing reagent inside this sort of system – relevance to the sample prep topic 	<ul style="list-style-type: none"> - Microfabrication of valves and sensors - Sensor development - Biocompatibility - Power - Miniaturization of electronics - Telemetry - Reagent storage/loading - Long term stability

Session I Group Name: Bioanalytical Technologies

Technology Name	Technology Details (Abbreviated)	Technology Hurdles (Abbreviated)
Flow cytometry	<ul style="list-style-type: none"> - To study <i>in situ</i> space biology requires low power, low weight, small volume, and fluidic system technologies that are compatible with microgravity - Since generation of aerosols would not be desirable in space, this dictates a closed system, microfluidic approach - In addition to examining human cells or microorganisms in a safe, sterile, closed system, analytes could be examined using bead-based chemistries - These devices could serve as miniature genomic/proteomic analyzers 	<ul style="list-style-type: none"> - These devices must be small, light-weight, portable, and robust - It must have a range of excitation and emission wavelengths available to permit use of a wide variety of molecular probes containing fluorescent reporter molecules - If it were high-throughput, it could reduce or eliminate many of the problems of prior cell preparation - Sample prep, insertion, manipulation - Multicolor/multi-parameter fluorescent excitation/detection - Need 20Mbaud downlink or massive onboard storage - Stability – long term reliability - Standardization/Calibration - Sensitivity - Biofouling
Microfluidics	<ul style="list-style-type: none"> - Eksigent Technologies is developing a line of micro-fluidic-based HPLC systems aimed at providing rapid analysis of sub-microliter samples with minimal reagent consumption <ul style="list-style-type: none"> - Weight: 10 lbs, Power: 20 watts - The microfluidic architecture makes these instruments compatible with the requirements of space biology systems. - Integrated analytical systems capable of in-flight evaluation of environmental/biological samples are being developed based on a centrifugal microfluidics platform using an instrument of the size of a compact disc (CD) player <ul style="list-style-type: none"> - The necessary fluidic components, such as valving, metering, mixing, etc., are integrated on a plastic CD 	<ul style="list-style-type: none"> - Flight qualified light source - Miniaturization - Long-term unattended operation - Integrated sample preparation - Chemical and biological fouling - Dynamic range of detection - MS interface - Column capacity - Reagent Storage - Single Use vs. Multiuse - Parallel Analysis vs. Multiplex Analysis - Sensitivity: Need for Sensitive Labels - Continuous vs. Discrete Measurements

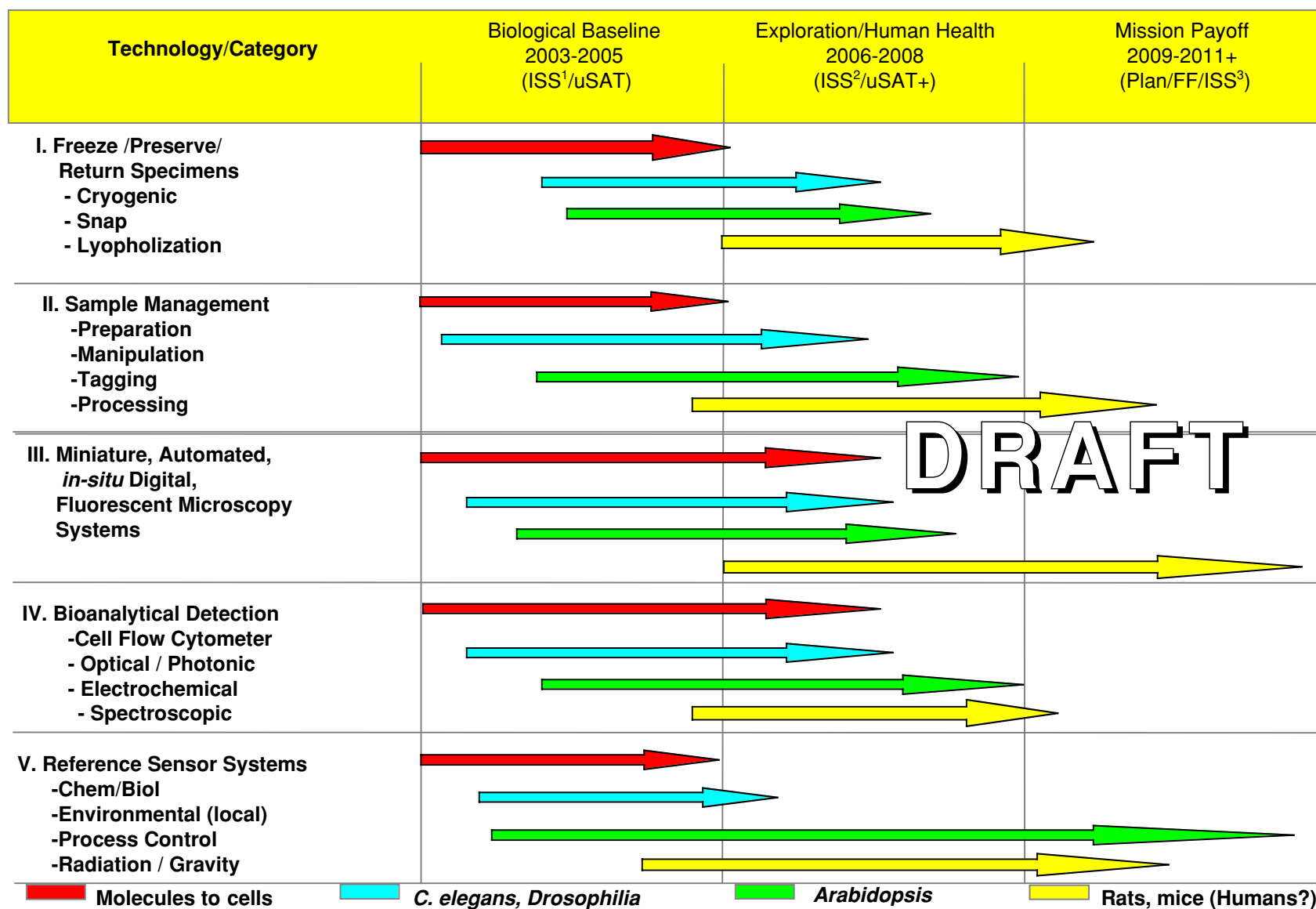
	<ul style="list-style-type: none"> - By using various rotational speeds, a wide range of fluidic processes may be carried out - The system also integrates process control, data acquisition, and analysis in a single multi-purpose device 	
Single-cell proteomics	<ul style="list-style-type: none"> - Self- contained modules that interconnect for flexibility - Sensitive, single- cell analysis - Multiple detection capabilities 	<ul style="list-style-type: none"> - Miniaturization - Power consumption - Environmental control - Multiparameter detection with high sensitivity - Interconnection of microsystem modules - Biocompatibility
Electrokinetic pumps for liquid delivery	<ul style="list-style-type: none"> - Postage stamp size, 1mm thick - Power: three 3 volt Li batteries; can operate 1-2 years @ 1 microamp - Up to 100K psi - Microgravity should have no effect on operation 	<ul style="list-style-type: none"> - Materials/liquids for wide temperature range - Design for manufacture - Design application integration - Improved performance materials - Increased flow rate dynamic range

Session I Group Name: Imaging/Photonics

Technology	Technology Details* (TBD)	Technology Hurdles (TBD)
Imaging		
Digital camera	Mature 0-5 years	
Optical microscope	Feasible 1-5 years	
Integrated imager (MOMS)	Mature 1-5 years	
Spectral imaging	Mature 1-5 years	
Time-resolved imaging	Mature 1-5 years	
Confocal	Mature 1-5 years	
3D imaging		
Quantum imaging	6-10 years	
Optical CT		
SPR imaging arrays	5 years	
Global imaging for Rodent Habitat		
Data Compression/analysis		
Image processing		
Flow cytometry microfluidics	6-10 years	
Sensors		
UV/Vis	Mature 1-5 years	
Fluorescence	Mature 1-5 years	
IR	Mature 1-5 years	
Optical time-resolved	Mature 1-5 years	
Polarization	Mature 1-5 years	
Evanescent wave	Mature 1-5 years	
MRI "hand-held"	6-10 years	
X-ray		
Coupled particle		
Probes/Reagents		
Novel probes (GFP, quantum dots)		
nanoparticles		
Functional binding probes		
molecular recognition probe		
Sources		
Solid state lasers, semiconductor		
Organics, LEDs		
Compact mode-locked lasers		

* Preliminary assessment only

Attachment F: Technology Roadmap Diagram



¹ ISS Assembly Phase, ² ISS Assembly Complete, ³ ISS Operational Phase

Attachment G: List of Science and Technology Quad Charts

Science

Alberts, Jeff

University of Indiana

Gravity-Sensitive, Integrated Studies on Young Mice

Bhattacharya, Sharmila (1)

NASA Ames Research Center

Tissue Specific and Intracellular Protein Expression of Genes in Space Studies with Fruit Flies

Bhattacharya, Sharmila (2)

NASA Ames Research Center

Genomic Regulation of Cell Morphology and Cytoskeleton Organization in the Fruit Fly

Boyle, Richard

NASA Ames Research Center

Chronic Neural Recordings using *In-situ* Electrode Arrays

Conley, Catherine

NASA Ames Research Center

***Caenorhabditis elegans* for Space Biology**

Kosik, Ken

Harvard University

Genetic Selection for Biological Survival Strategies in the Fruit Fly and Honey Bee

Niesel, David

University of Texas Medical Branch

***Streptococcus pneumoniae* Gene & Protein Expression in the Space Environment**

Pecaut, Michael

Loma Linda University Medical Center

Mouse Models for Characterization of Spaceflight Environment

Ramos, Ross

NASA Ames Research Center

Gene Expression and Cell Control in Space Flown Lymphocytes

Santos, Orlando

NASA Ames Research Center

***Caenorhabditis elegans* for Space Studies**

Technology

Bachas, Leonidas

University of Kentucky

Integration of Biochemical Sensors on a Centrifugal Microfluidics Platforms

Battrell, C.F. (Fred)

Micronics

Microcytometry System-Cell/Particle Characterization

Dalton, Bonnie

NASA Ames Research Center

Stable Preparation of mRNA

Darling, Robert Bruce

University of Washington, Seattle

Microfabricated Components for Miniaturized Chemical Analysis Systems

Etheridge, Guy

NASA Kennedy Space Center

Gene Expression Imaging

Flynn, Michael

NASA Ames Research Center

Rotating Disk Analytical System

Jeevarajan, Antony

NASA Johnson Space Center

Continuous pH Monitor and Controller for Perfused Bioreactors; Continuous Glucose Monitor and Controller for Perfused Bioreactors; Continuous Oxygen Sensor for Perfused Bioreactors

Kim, CJ

University of California, Los Angeles

Programmable Digital Microfluidic Network

Kittel, Peter

NASA Ames Research Center

Cryogenics

Krihak, Michael

DARPA

Micro-Coulter Counter

Leary, James (1)

University of Texas Medical Branch at Galveston

Targetable Nanoparticles with Biosensors for Nanomedicine

Leary, James (2)
University of Texas Medical Branch at Galveston
High-Speed “Lab-on-a-chip” Flow Cytometry for Space

Levi, Ofer
Stanford University
Integrated Bio-Fluorescence Sensor

Malak, Henryk
University of Maryland
Noninvasive Sensitive Photonics Technologies for Biomolecular and Cellular Sensing

Mathies, Richard
University of California, Berkeley
Microfabricated Chemical and Biochemical Analyzers for Space Exploration and Bio-Monitoring

May, Kimberly
NASA Ames Research Center, University of Kentucky
Improved, Miniaturized ISEs for Application in Environmental Sensing

McGrath, John
University of Arizona
Technology for Preservation of Cell Samples by Avoiding Crystallization

Meldrum, Dierdre
University of Washington
Microsystems for Analyzing Living Cells

Ottenberg, Matt
DakoCytomation
***In-situ* Cell Flow Cytometry**

Richmond, Robert
NASA Marshall Space Flight Center
Biodosimetry for Space Radiation Exposure

Searby, Nancy [posted in Science on Web site]
NASA Ames Research Center
Cell Counter for Space Studies

Skelley, Alison
University of California, Berkeley
Microfabricated Analyzer for *In Situ* Detection of Extraterrestrial Bioorganic Molecules

Smith, Jeffrey
NASA Ames Research Center
Serial-Section Reconstruction and Analysis of Cell Structure

Smith, Jeffrey; Twombly, Xander; Boyle, Richard
NASA Ames Research Center
Virtual Glovebox (VGX)

Stirbl, Robert
NASA Jet Propulsion Laboratory/Caltech
***C. elegans* for Toxic Agent Sensing and Proposed Space Studies**

Todd, Paul
SHOT
Cellcult Cassette

Weedn, Victor
Carnegie Mellon University
**Implantable Diagnostic Chip; Labelless Fluorescent Probes for Diagnostics;
Microdialysis for Cell Culture Media; Noninvasive Breath Analyzer**

Zoval, Jim
UCI, UK, ChipRx
Microfabricated Responsive Drug Delivery

Attachment H: OBPR-wide Fundamental Research Objectives

Understand Nature's Forces in Space

- Use the space environment as a laboratory to test the fundamental principles of physics, chemistry, and biology
- Conduct research to enable safe and productive human habitation of space

Understand and Enable the Human Experience in Space

- Conduct research to enable safe and productive human habitation of space
- Enable and promote commercial research in space

Conduct Basic and Applied Biological Research to:

- Understand and control the human health risks of space flight
- Understand the response of terrestrial organisms to the space flight environment
- Understand the role of gravity in life processes and development
- Improve life support technology and human performance

Conduct Basic and Applied Physical Sciences Research to:

- Exploit space to pursue basic research questions in biotechnology, combustion science, materials science, fluid physics, and fundamental physics
- Improve spacecraft systems for energy storage and management; for propulsion using advanced materials engineering; for preventing, detecting, and suppressing fire; for more efficient life-support; and for mitigating radiation impact
- Advance fundamental scientific understanding to improve industrial processes

Focus on Research Relevant to NASA's Mission

- Enable safe human presence and exploration in space
- Prepare the way for human exploration through space technology development
- Evaluate the role of gravity in complex inert and living systems
- Explore the response of terrestrial organisms to the space flight environment
- Conduct cutting edge ecological research on small closed ecosystems
- Develop advanced environmental monitoring technologies
- Develop technologies for cleaner, more efficient utilization of energy sources
- Probe the fundamental laws of the universe directly through definitive critical experiments enabled by the microgravity environment
- Promote direct student participation in flight research

Enable ISS Research: Maximize Research Capability and Throughput

Develop and Utilize Technologies That Minimize Use of Vehicle Resources

- Lightweight and small volume
- Low in power consumption
- Low in maintenance and operation effort

Enhance Existing Research by Providing Appropriate Technologies

- New analytical and imaging technology
- Larger sample throughput
- More accurate measurements